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REMARKS

A Petition and Fee for Two Month Extension of Time is submitted herewith.

Applicant notes that a personal interview was conducted in this case on February 26, 2003 and that the claim amendments made by this Amendment are based in part on the Examiner's helpful comments made at the interview.

Claims 53-110 and 113-118 are all the claims presently pending in the application.

Claims 53-56 have been amended to more particularly define the invention. Attached hereto is a marked-up version of the changes made to the claims by the current Amendment.

It is noted that the claim amendments are made only for more particularly pointing out the invention, and not for distinguishing the invention over the prior art, narrowing the claims or for any statutory requirements of patentability. Further, Applicant specifically states that no amendment to any claim herein should be construed as a disclaimer of any interest in or right to an equivalent of any element or feature of the amended claim.

Claims 54, 56, 58, 60, 62, 64, 66, 68, 70, 72, 74, 76, 78, 80, 82, 84, 86, 88, 90, 92, 94, 96, 98, 100, 102, 104, 106, 108, 110, 114, 116 and 118 stand rejected under 35 U.S.C. § 112, first paragraph, and claims 53-110 and 113-118 stand rejected under 35 U.S.C. § 112, second paragraph

Claims 53-110 and 113-118 stand rejected under 35 U.S.C. § 103(a) as being unpatentable over Sayyah ("A Study of Growth Mechanisms and Electrical and Optical Properties of Epitaxial $Al_xGa_{1-x}N$ Layers Grown by Atmospheric Pressure Metalorganic Chemical Vapor Deposition", A Dissertation Presented to the Faculty of the Graduate School, University of Southern California, February 1986) in combination with Koide et al. ("Epitaxial Growth and Properties of $Al_xGa_{1-x}N$ by MOVPE", J. Electrochem. Soc.: Solid-state Science and Technology, September 1986).

These rejections are respectfully traversed in view of the following discussion.

I. THE CLAIMED INVENTION

The claimed invention (e.g., as recited in claim 53) is directed to a method for producing a gallium nitride group compound semiconductor by an organometallic compound

vapor phase epitaxy. The inventive method includes setting a supplying ratio of silicon (Si) to gallium (Ga) in a reaction chamber during the vapor phase epitaxy at a desired value in a range from greater than 0.1 to 3 as converted values so as to control conductivity (1/resistivity) of the gallium nitride group compound semiconductor at a desired value such that the conductivity increases with an increase of said supplying ratio. Further, the values 0.1 and 3 are the values obtained from gas flow rates, an amount of the gallium (Ga) being converted into a flow rate of hydrogen bubbling trimethyl gallium (TMG) at a temperature of -15°C and an amount of the silicon (Si) being converted into a flow rate of a gas diluted to 0.86 ppm.

In another aspect (e.g., as recited in claim 54), the inventive method includes setting a supplying ratio of silicon (Si) to NH₃ in a reaction chamber during the vapor phase epitaxy at a desired value in a range from 8.6 x 10⁻¹⁰ to 2.6 x 10⁻⁸, so as to control conductivity (1/resistivity) of the gallium nitride group compound semiconductor at a desired value such that the conductivity increases with an increase of the supplying ratio.

Conventional methods may use silane to vary a composition ratio (e.g., ratio of Al to Ga) in an AlGaN layer. However, such methods do not set a supplying ratio of silicon (Si) to gallium (Ga) (e.g., or NH₃) at a desired value so as to control the conductivity (e.g., or carrier concentration) of the gallium nitride group compound semiconductor at a desired value such that the conductivity (e.g., or carrier concentration) increases with an increase in the supplying ratio.

The claimed method, on the other hand, includes setting a supplying ratio of silicon (Si) to gallium (Ga) (e.g., or NH₃) at a desired value (e.g., Si/Ga in a range of 0.1 to 3, and Si/NH₃ in a range of 8.6 x 10⁻¹⁰ to 2.6 x 10⁻⁸) as to control the conductivity (e.g., or a carrier concentration) of the gallium nitride group compound semiconductor at a desired value such that the conductivity (e.g., or carrier concentration) increases with an increase of said supplying ratio.

The inventive method enables a production of a gas-phase grown GaN layer of high purity. That is, it provides an n-type GaN layer with high resistivity without requiring a doping with impurities, unlike conventional technology which provides n-type GaN with low

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resistivity when no doping is performed.

II. THE 35 USC §112, FIRST PARAGRAPH REJECTION

The Examiner alleges that claims 54, 56, 58, 60, 62, 64, 66, 68, 70, 72, 74, 76, 78, 80, 82, 84, 86, 88, 90, 92, 94, 96, 98, 100, 102, 104, 106, 108, 110, 114, 116 and 118 are not enabled. Applicant submits, however, that these claims are adequately enabled by the specification.

Referring to Figure 26 and Example 4 (Application at page 28, lines 2-14) of the original specification, the Application explains that in the inventive method, an electron concentration increases from point when the flow rate of H₂-diluted silane (0.86 ppm) is varied from 10cc/min. (hereinafter referred to as "point A") to 300cc/min. (hereinafter referred to as "point B"). Attached hereto as Exhibit 1 is a copy of Figure 26 with these points clearly indicated.

Specifically, as shown in Figure 26, at point A, flowing silane of 0.86 ppm in concentration at a flow rate of 10cc/min. corresponds to flowing pure silane.

As 0.86ppm = 0.86×10^{-6} , 0.86×10^{-6} of 10cc diluted silane is a volume of pure silane.

Accordingly, a volume of pure silane is $10\text{cc} \times 0.86 \times 10^{-6} = 8.6 \times 10^{-6}\text{cc}$.

As a result, the flow rate of pure silane becomes $8.6 \times 10^{-6}\text{cc}$.

On the contrary, Example 4 of the original specification of the present invention discloses that flow rate of NH₃ is 10 liter/min. Therefore, the ratio of silane/NH₃ at point A becomes $8.6 \times 10^{-6}\text{cc} / 10,000 \text{ cc} = 8.6 \times 10^{-10}$.

Thus, the supplying ratio at Point A may be calculated as follows:

$$\begin{aligned}
 0.86 \text{ parts SiH}_4 / 10^6 \text{ parts total} &= 0.86 \times 10^{-6} \text{ cc SiH}_4 / \text{cc total gas} \\
 0.86 \times 10^{-6} \text{ cc SiH}_4 / \text{cc total gas} \times 10 \text{ cc total gas/min} &= 8.6 \times 10^{-6} \text{ cc SiH}_4 / \text{min} \\
 \text{supplying ratio} &= \text{supplying rate Si} / \text{supplying rate NH}_3 \\
 &= (8.6 \times 10^{-6} \text{ cc SiH}_4 / \text{min}) / (10,000 \text{ cc NH}_3 / \text{min}) \\
 &= 8.6 \times 10^{-10}
 \end{aligned}$$

Further, at Point B in Figure 26, the flow rate of 0.86 ppm diluted silane is 300cc/min. Therefore, the flow rate of pure silane is $0.86\text{ppm} \times 300 \text{ cc/min} = 2.58 \times 10^{-4} \text{ cc/min}$.

On the contrary, because the flow rate of NH₃ is 10 liter/min, the ratio of silane/NH₃ at

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point B becomes $2.58 \times 10^{-4} \text{cc} / 10,000 \text{cc} = 2.58 \times 10^{-8}$. Thus, using two (2) significant figures, the ratio of silane/NH₃ at point B is 2.6×10^{-8} .

Thus, the supplying ratio at Point B may be calculated as follows:

$$0.86 \text{ parts SiH}_4 / 10^6 \text{ parts total} = 0.86 \times 10^{-6} \text{ cc SiH}_4 / \text{cc total gas}$$

$$0.86 \times 10^{-6} \text{ cc SiH}_4 / \text{cc total gas} \times 300 \text{ cc total gas/min} = 2.58 \times 10^{-4} \text{ cc SiH}_4 / \text{min}$$

$$\text{supplying ratio} = \text{supplying rate Si} / \text{supplying rate NH}_3$$

$$= (2.58 \times 10^{-4} \text{ cc SiH}_4 / \text{min}) / (10,000 \text{ cc NH}_3 / \text{min})$$

$$= 2.58 \times 10^{-8}$$

Therefore, as explained above, all the figures and values shown in the present claims 54 and 56 may be read from and are clearly supported by the disclosure of the original specification. Thus, claims 54 and 56, and any claims depending directly or indirectly therefrom, are clearly enabled by the disclosure of the original specification.

In view of the foregoing, the Examiner is respectfully requested to withdraw this rejection.

II. THE 35 USC §112, SECOND PARAGRAPH REJECTION

The Examiner alleges that claims 53-110 and 113-118 are indefinite for failing to particularly point out and distinctly claim the subject matter regarded as the invention. Applicant submits, however, that these claims are not indefinite.

Specifically, Applicant notes that claims 53 and 55 have been amended to recite "*setting a supplying ratio of silicon (Si) to gallium (Ga)...*" to clarify that the recited "*range from greater than 0.1 to 3*" is a supplying ratio range.

In view of the foregoing, the Examiner is respectfully requested to withdraw this rejection.

III. THE SAYYAH AND KOIDE REFERENCES

The Examiner alleges that Sayyah would have been combined with Koide to form the claimed invention. Applicant submits, however, that these references would not have been combined and even if combined, the combination would not teach or suggest each and every element of the claimed invention.

Sayyah discloses factors influencing the properties of epitaxial layers of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ grown on sapphire substrates by the atmospheric pressure MOCVD technique (Sayyah at page 162).

Koide discloses a method of growing epitaxial layers of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ on sapphire and silicon substrates by MOVPE. The electrical resistivity, carrier concentration, and Hall mobility of the layers were studied as a function of the composition (Koide at Abstract).

However, Applicant submits that these references would not have been combined as alleged by the Examiner. Indeed, these references are directed to different matters.

Specifically, Sayyah discloses using silane to control a composition ratio (e.g., ratio of Al to Ga) in an $\text{Al}_x\text{Ga}_{1-x}\text{N}$ layer (Sayyah at page 133, lines 13-25), whereas Koide uses NH_3 to reduce a parasitic reaction of organometallic compounds in order to control the composition ratio of an $\text{Al}_x\text{Ga}_{1-x}\text{N}$ layer (Koide at page 1957). Clearly, no person of ordinary skill in the art would have considered combining these references.

Further, Applicant submits that the Examiner can point to no motivation or suggestion in the references to urge the combination as alleged by the Examiner. Indeed, the Examiner merely states that it would have been obvious to combine these references “because Koide process is to reduce parasitic reaction between metal organic compounds with ammonia thereby producing AlGaN layers with controlled composition”. This assertion, without more, is insufficient to support the combination.

Moreover, Applicant submits that neither Sayyah nor Koide teaches or suggests a method for producing a gallium nitride group compound semiconductor by an organometallic compound vapor phase epitaxy, where the method includes setting a supplying ratio of silicon (Si) to gallium (Ga) (e.g., or NH_3) at a desired value (e.g., Si/Ga in a range of 0.1 to 3, and Si/ NH_3 , in a range of 8.6×10^{-10} to 2.6×10^{-8}) so as to control the conductivity (e.g., or a carrier concentration) of the gallium nitride group compound semiconductor at a desired value such that the conductivity (e.g., or carrier concentration) increases with an increase of said supplying ratio, as claimed, for example, in claims 53-56.

As noted above, conventional methods do not set a supplying ratio of silicon (Si) to gallium (Ga) (e.g., or NH_3) at a desired value so as to control the conductivity (e.g., or carrier concentration) such that the conductivity (e.g., or carrier concentration) increases with an

increase of said supplying ratio.

The claimed method, on the other hand, includes setting a supplying ratio of silicon (Si) to gallium (Ga) (e.g., or NH₃) at a desired value (e.g., Si/Ga in a range of 0.1 to 3, and Si/NH₃ in a range of 8.6 x 10⁻¹⁰ to 2.6 x 10⁻⁸) so as to control the conductivity (e.g., or a carrier concentration) such that the conductivity (e.g., or carrier concentration) increases with an increase of said supplying ratio (Application at page 11, lines 3-11).

The inventive method enables a production of a gas-phase grown GaN layer of high purity. That is, it provides an n-type GaN layer with high resistivity without requiring a doping with impurities, unlike conventional technology which provides n-type GaN with low resistivity when no doping is performed (Application at page 3, lines 6-12).

As explained in the Application, the inventors have established a technology for a vapor phase epitaxy of a GaN semiconductor with an organometallic compound. Unlike conventional methods, in the inventive method a layer conductivity (e.g., carrier concentration) may be increased by increasing a ratio of silicon to Ga (e.g., or NH₃) being supplied to a reactor. This is clearly illustrated, for example, by Example 4, which is discussed in the Application at page 28, lines 2-14 and Figure 26.

As discussed above, in Example 4, the supplying rate of TMG-carrying H₂ is 100 cc/min, and the supplying rate of H₂-diluted silane (0.86ppm) was varied from 10 cc/min to 300 cc/min. Thus, as calculated above, the supplying ratio of silicon to gallium in Example 4 was varied between 8.6 x 10⁻¹⁰ and 2.58 x 10⁻⁸. Notably, as shown in Figure 26, the carrier concentration increased (e.g., linearly and steeply) as this supplying ratio was increased.

Clearly, the cited references do not teach or suggest these novel features. Indeed, Applicant respectfully submits that at the time of this invention, it was commonly accepted that silicon was an acceptor impurity and could not be implanted in a layer to increase the conductivity of the layer, but instead would decrease the conductivity of the layer.

As evidence of this conventional belief, Applicant again directs the Examiner's attention to Khan (U. S. Pat. No. 4,614,961) which discloses that when silicon concentration of AlGaN is increased, conductivity of AlGaN cannot increase, Pankove et al. ("Optical Absorption of GaN", Applied Physics Letters, Vol. 17, No. 5, September 1970, pp. 197-198), which shows that electron concentration decreases by doping silicon in GaN (page 198, upper

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left column, lines 2-3), and Tietjen et al. ("Vapor Phase Growth Technique and System for Several III-V Compound Semiconductors", March 1969, Electronics Research Center Cambridge, Massachusetts National Aeronautics and Space Administration), which shows that by doping silicon to undoped GaN, the electron concentration of GaN decreases to a range of $2.0 \times 10^{19}/\text{cm}^3$ to $3.0 \times 10^{16}/\text{cm}^3$ (e.g., Tietjen at Table II of page 4).

In short, no prior art discloses a method in which carrier concentration is controlled by doping impurities. For instance, Khan and Tietjen show that electron concentration of GaN before doping silicon is $10^{19}/\text{cm}^3$ to $10^{20}/\text{cm}^3$, and that electron concentration decreases as a result of doping silicon. Therefore, although these references may dope silicon into GaN, this is done in order to obtain a semiconductor having p-type concentration. Neither reference dopes silicon as a acceptor impurity in order to decrease electron concentration to thereby control electron concentration.

Further, contrary to the Examiner's allegations, Sayyah does not teach or suggest setting a supplying ratio of silicon (Si) to gallium (Ga) (e.g., or NH_3) at a desired value (e.g., Si/Ga in a range of 0.1 to 3, and Si/NH_3 in a range of 8.6×10^{-10} to 2.6×10^{-8}) so as to control the conductivity (e.g., or a carrier concentration) such that the conductivity (e.g., or carrier concentration) increases with an increase of said supplying ratio.

In sum, Sayyah does not aim to increase electron concentration by doping silicon. Instead, Sayyah merely shows that composition ratios of Al and Ga in an AlGaN layer may be varied by using silane.

Further, Sayyah fails to control electron concentration. In short, Sayyah cannot increase electron concentration. Indeed, it is important to understand that involving Si in an AlGaN layer is completely different from increasing electron concentration. That is, there is no causal relationship between the two processes. Thus, in Sayyah's invention, even when Si is included in AlGaN, electrons are not excited by that Si to the conduction band of the AlGaN.

On the contrary, in the claimed invention, Si excites electrons to the conduction band of AlGaN, and electron concentration increases as the ratio of a gas containing Si to a gas containing other material increases. This is clearly different from Sayyah, which may disclose a silicon concentration in a semiconductor layer, but fails to disclose an electron

concentration which is controlled when silicon is doped into the semiconductor layer. In face, electron concentration is not disclosed in Sayyah, likely because Sayyah could not control electron concentration.

Further, Applicant notes at the time of the claimed invention, no conventional technology could effectively control electron concentration even by doping silicon.

More specifically, Sayyah may disclose doping silicon in GaN, but Sayyah clearly fails to suggest that such doping causes an increase in conductivity and electron concentration as shown, for example, in Figure 25 of the present invention. Moreover, at the time when the present invention was invented, it had not been known that Si is a donor which excites electrons and that electron concentration may be controlled linearly by Si concentration, as shown in Figure 26 of the present invention.

In fact, Sayyah clearly shows that even when silicon is doped in $\text{Al}_x\text{Ga}_{1-x}\text{N}$ to a doping concentration of $8 \times 10^{21}/\text{cm}^3$, the conductivity of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ cannot be changed. It is further disclosed that even if silicon is doped in $\text{Al}_x\text{Ga}_{1-x}\text{N}$ having a comparatively high molar fraction of aluminum, a conductivity of a film was not changed from semi-insulative to conductive (Sayyah at page 135, lines 18-20). It is also disclosed that when $1.4 \times 10^{21}\text{cm}^{-3}$ and $8.0 \times 10^{21}\text{cm}^{-3}$ of silicon were doped in $\text{Al}_x\text{Ga}_{1-x}\text{N}$ having aluminum composition ratio x of 0.56 and 0.81, respectively, any measurable conductivity cannot be observed (Sayyah at page 135, lines 20-22). This is clearly contrary to the present method in which electron concentration linearly increases with an increase in the amount silicon doping, (Application at Figure 26). Thus means that silicon functions as donor impurity in the present invention.

In addition, even assuming that Sayyah discloses that the ratio $\text{SiH}_4 / (\text{TMG} + \text{TMA})$ is in a range of 0 to 0.1 (Sayyah at Figure 27), Sayyah clearly does not teach or suggest setting this ratio to control conductivity or electron concentration. Instead, Sayyah only teaches that uptake quantity of Ga and Al varies according to a doping quantity of Si (Sayyah at page 129, lines 2-5).

Further, the Examiner states that Sayyah discloses “intentionally doping Si to form n-type dopant layer with concentration approximately at $1-5 \times 10^{19}/\text{cm}^3$ ”. However, even

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assuming this is disclosed by Sayyah, this falls well short of teaching or suggesting a method which includes setting a supplying ratio to control conductivity or electron concentration such that the conductivity (e.g., or carrier concentration) increases with an increase of said supplying ratio.

Likewise, Koide does not teach or suggest these novel features of the claimed method. Indeed, the Examiner merely cites Koide for allegedly disclosing a temperature range for growing GaN.

Further, Koide may disclose varying a composition of a layer to study the effect on the electrical resistivity and carrier concentration. However, Koide merely varies the ratio of Aluminum to Gallium in a $\text{Al}_x\text{Ga}_{1-x}\text{N}$ layer (Koide at page 1950). That is, nowhere does Koide teach or suggest the effect of varying an amount of silicon on the electrical resistivity and carrier concentration of the layer, and certainly does not teach or suggest setting a supplying ratio of silicon to gallium (e.g., or NH_3) at a desired value (e.g., Si/Ga in a range of 0.1 to 3, and Si/NH₃ in a range of 8.6×10^{-10} to 2.6×10^{-8}) to control conductivity or electron concentration such that the conductivity (e.g., or carrier concentration) increases with an increase of said supplying ratio. Therefore, Koide does not make up for the deficiencies in Sayyah.

Therefore, Applicant submits that these references would not have been combined and even if combined, the combination would not teach or suggest each and every element of the claimed invention. Therefore, the Examiner is respectfully requested to withdraw this rejection.

IV. FORMAL MATTERS AND CONCLUSION

In view of the foregoing, Applicant submits that claims 53-110 and 113-118, all the claims presently pending in the application, are patentably distinct over the prior art of record and are in condition for allowance. The Examiner is respectfully requested to pass the above application to issue at the earliest possible time.

Should the Examiner find the application to be other than in condition for allowance, the Examiner is requested to contact the undersigned at the local telephone number listed

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below to discuss any other changes deemed necessary in a telephonic or personal interview.

The Commissioner is hereby authorized to charge any deficiency in fees or to credit any overpayment in fees to Attorney's Deposit Account No. 50-0481.

Respectfully Submitted,

Date: 3/17/03



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VERSION WITH MARKINGS TO SHOW CHANGES MADE

IN THE CLAIMS:

Please amend the claims to read as follows:

53. (Twice Amended) A method for producing a gallium nitride group compound semiconductor by an organometallic compound vapor phase epitaxy, comprising [the steps of]:

setting a supplying ratio [rate] of silicon (Si) to gallium (Ga) in a reaction chamber during said vapor phase epitaxy at a desired value in a range from greater than 0.1 to 3 as converted values so as to control conductivity (1/resistivity) of said gallium nitride group compound semiconductor at a desired value such that said conductivity increases with an increase [increasing] of said supplying ratio,

wherein [where] said values 0.1 and 3 are the values obtained from gas flow rates, [in case that] an amount of said gallium (Ga) being [is] converted into a flow rate of hydrogen bubbling trimethyl gallium (TMG) at a temperature of -15°C and an amount of said silicon (Si) being [is] converted into a flow rate of a gas diluted to 0.86 ppm.

54. (Twice Amended) A method for producing a gallium nitride group compound semiconductor by an organometallic compound vapor phase epitaxy, comprising [the steps of]:

setting a supplying ratio [rate] of silicon (Si) to NH₃ in a reaction chamber during said vapor phase epitaxy at a desired value in a range from 8.6×10^{-10} to 2.6×10^{-8} , so as to control conductivity (1/resistivity) of said gallium nitride group compound semiconductor at a desired value such that said conductivity increases with an increase [increasing] of said supplying ratio.

55. (Twice Amended) A method for producing a gallium nitride group compound semiconductor by an organometallic compound vapor phase epitaxy, comprising [the steps of]:

setting a supplying ratio [rate] of silicon (Si) to gallium (Ga) in a reaction chamber

during said vapor phase epitaxy at a desired value in a range from greater than 0.1 to 3 as converted values so as to control a carrier concentration of said gallium nitride group compound semiconductor at a desired value such that said carrier concentration increases with increasing of said supplying ratio,

wherein [where] said values 0.1 and 3 are the values obtained from gas flow rates, [in case that] an amount of said gallium (Ga) being [is] converted into a flow rate of hydrogen bubbling trimethyl gallium (TMG) at a temperature of -15°C and an amount of said silicon (Si) being [is] converted into a flow rate of a gas diluted to 0.86 ppm.

56. (Twice Amended) A method for producing a gallium nitride group compound semiconductor by an organometallic compound vapor phase epitaxy, comprising [the steps of]:

setting a supplying ratio [rate] of silicon (Si) to NH₃ in a reaction chamber during said vapor phase epitaxy at a desired value in a range from 8.6×10^{-10} to 2.6×10^{-8} , so as to control a carrier concentration of said gallium nitride group compound semiconductor at a desired value such that said carrier concentration increases with an increase [increasing] of said supplying ratio.